Sense Accuracy and Calibration

of the PROFET™+2 12V family

About this document

Scope and purpose

This document shows how to understand, use and calibrate the devices of the PROFET™+2 12V family.

Intended audience

Engineers, hobbyists and students who want to understand powerful protected high-side switches for heating or power distribution projects.

Table of contents

About this document . . . 1

Table of contents . . . 1

1 Current Sense . . . 2

1.1 Introduction . . . 2

1.2 Current sense circuit . . . 3

1.3 Diagnosis in ON state . . . 6

1.3.1 Accuracy at low current . . . 8

1.4 Diagnosis in OFF state . . . 9

2 Error calculation . . . 10

2.1 "Default" performance . . . 12

2.2 1-Point calibration performance . . . 15

3 Practical procedure . . . 19

3.1 "Default" behavior . . . 20

3.2 1-Point calibration . . . 20

4 Conclusion . . . 22

Revision history . . . 23

Disclaimer . . . 24

1 Current Sense

The PROFET™+2 12V family offers protection and diagnostic features and a very low ohmic DMOS power stage. This combination makes the PROFET™+2 12V family suitable for resistive, inductive and capacitive loads, high inrush current loads such as lamps and can replace relays, fuses and discrete circuits.

The PROFET™+2 12V family offers two variants that differ in the protection strategy mechanism.

PROFET™+2 12V devices with Intelligent Restart Control have an internal counter which counts the number of fault events (up to 7). When the device latches, a reset can be applied to restart the counter. They are suitable to drive application with high inrush current such as bulbs, in which is crucial to diagnosis with good resolution the open load condition.

PROFET™+2 12V devices with Intelligent Latch have an internal latch which protects the output stage in case of a fault event. When the device latches, a reset can be applied to restart the counter. They are designed for high current application, in which it is important to monitor the load current until $I_{L(OVL),max}$.

This chapter will provide a brief introduction to the PROFET™+2 12V family diagnosis features, as open load in OFF state, open load in ON state, short circuit to battery and inverse current.

1.1 Introduction

The PROFET™+2 12V family provides as diagnostic feature an analog current sense, that can be used to:

- Monitor the application state as normal, overload, open load, short circuit to ground, short circuit to battery condition, protective switch off (thermal shutdown and overcurrent shutdown)
- Protect the load and the wiring harness
- Measure the output current for the purpose of controlling the output power

The parameter used to quantify the accuracy of the current sensing is called k_{ILIS}, because it is defined as the ratio between the load current I_L and the sense current I_{IS}:

$$k_{ILIS} = \frac{I_L}{I_{IS}}$$

Equation 1

The k_{ILIS} factor is specified with limits that take into account effects due to:

- Temperature
- Supply voltage
- Manufacturing process

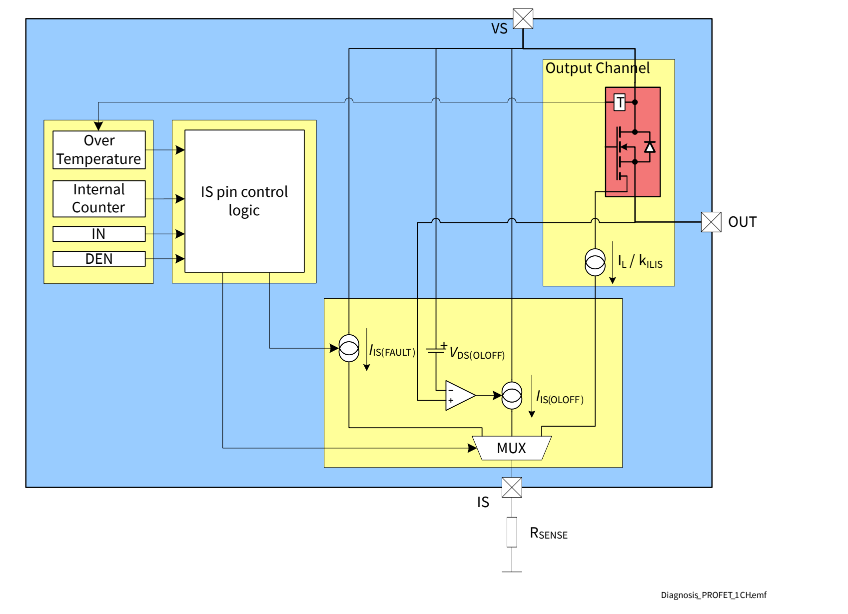

Figure 1 **Diagnosis block diagram**

The block diagram, highlighting the diagnosis part for a high-side power switch is illustrated in ***Figure 1***.

The diagnosis circuitry is controlled by the "Diagnosis Enable" (DEN) pin: when it is set to "high", the diagnosis is enabled.

For the new PROFET™+2 12V family additional calibration techniques are supported, whenever the overall specified sense performance does not meet the accuracy required for a particular application.

1.2 Current sense circuit

Ideally the analog current sense diagnosis should reflect the load current without any additional error contribution. However in reality analog current sense diagnosis do always have an inherent inaccuracy associated. In ***Figure 2***, the current sense equivalent circuit is shown.

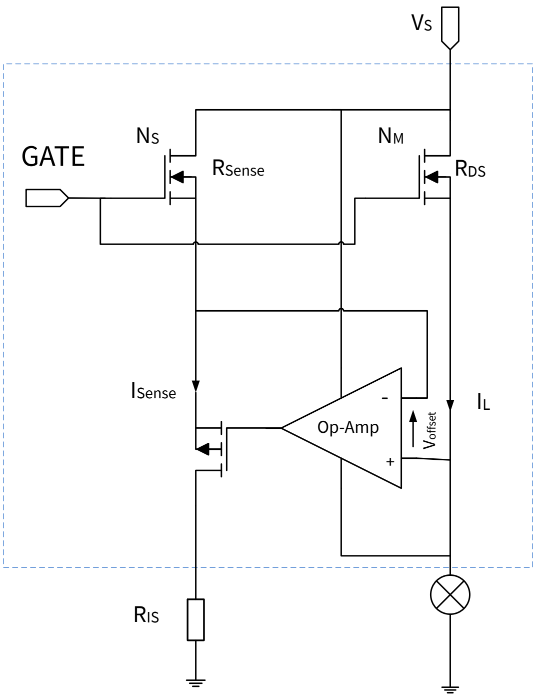

Figure 2 **Current sensing circuit for a conventional high-side power switch**

The following equations show the relation between $k_{\mathrm{ILIS(ideal)}}$ and $k_{\mathrm{ILIS(real)}}$.
If the voltage across the input pins of Op-Amp (V_{offset}) is not taken into account, the relation between the voltage cross the MOSFET of the current mirror V_{M}, and the voltage across the power MOSFET V_{P} will be:

$$V_M = V_P$$

Equation 2

$$I_{IS} \cdot R_M = I_L \cdot R_P$$

Equation 3

$$\frac{N_P}{N_M} = \frac{R_M}{R_P} = \frac{I_L}{I_{IS}} = k_{ILIS(ideal)}$$

Equation 4

Where R_{M} is the ON resistance of the MOSFET of the current mirror with N_{M} cells; R_{P} is the ON resistance of the power MOSFET with N_{P} dimension.
Including the Op-Amp contribution:

$$V_M \pm V_{offset} = V_P$$

Equation 5

$$I_{IS} \cdot R_M \pm V_{offset} = I_L \cdot R_P$$

Equation 6

$$\frac{1}{I_L \cdot R_P \pm V_{offset}} = \frac{1}{I_{IS} \cdot R_M}$$

Equation 7

$$\frac{I_L \cdot R_M}{I_L \cdot R_P \pm V_{offset}} = \frac{I_L}{I_{IS}} = k_{ILIS(real)}$$

Equation 8

$$k_{ILIS(real)} = \frac{I_L \cdot R_M}{I_L \cdot \left(R_P \pm \frac{V_{offset}}{I_L}\right)} = \frac{R_M}{R_P} \cdot \frac{1}{1 \pm \frac{V_{offset}}{R_P \cdot I_L}}$$

Equation 9

$$k_{ILIS(real)} = k_{ILIS(ideal)} \cdot \frac{1}{1 \pm \frac{V_{offset}}{R_P \cdot I_L}}$$

Equation 10

As result of the previous equations, the relation of I_L and k_{ILIS} is plotted in ***Figure 3*** . Ideally the relationship between the sense current I_{IS} and the load current I_L is linear and their ratio is constant and equal to $k_{ILIS(ideal)}$, as the blue curve shows. When the Op-Amp is introduced, depending on its positive or negative internal offset voltage, the current sense accuracy, shown in the red curves, is deteriorated especially at lower load currents.

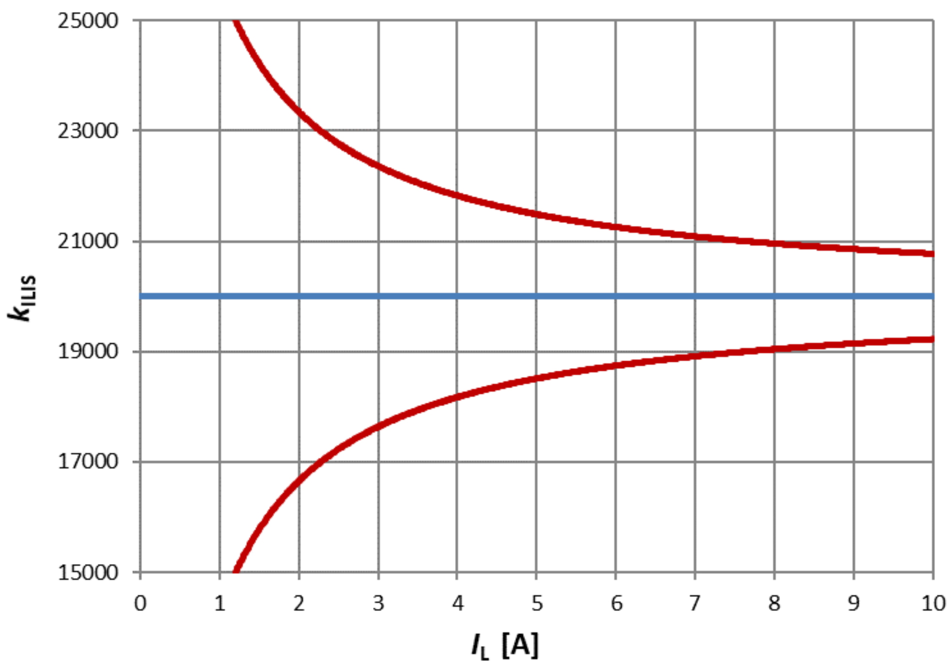

Figure 3 **Example of current sense versus load current**

1.3 Diagnosis in ON state

A current proportional to the load current (ratio $k_{ILIS} = I_L / I_{IS}$) is provided at pin IS when the following conditions are fulfilled:

- The power output stage is switched ON with $V_{DS} < V_{DS(OLOFF)}$
- The diagnosis is enabled (DEN level = "high")
- No fault (overtemperature and overload condition) is present or was present and not cleared yet

I_{IS} increases linearly with I_L output current until it reaches the saturation current $I_{IS(SAT)}$.

If the load is in underload condition (i.e. output voltage limitation condition) and the output current is higher than $I_{L(OL)}$, I_{IS} will be $I_{IS(EN)} < I_{IS} < I_{L(NOM)}/k_{ILIS}$, as shown in the pointed area of ***Figure 4*** (see ***Chapter 1.3.1*** for further details). In underload condition the device can distinguish $I_{L(OL)min}$ from $I_{L(OL)max}$.

If the load is in open load condition (I_L close to 0 A and V_{out} close to V_s) and the output load current is smaller than $I_{L(OL)}$, the maximum sense current $I_{IS(EN)}$ measurable is specified (as shown in the striped area of ***Figure 4***). This $I_{IS(EN)}$ value is specified in the datasheet for $T_J \leq 85°C$ (P_9.6.0.3) and for $T_J = 150°C$ (P_9.6.0.4).

The open load output current range is specified in the datasheet measuring the sensing current I_{IS}, when it is equal to 4 µA. Assuming R_{SENSE} = 1.2 k, V_{SENSE} is 4.8 mV, and this is considered as the minimum value that a microcontroller (µC) can measure in order to use this diagnosis feature.

This condition is shown in ***Figure 4***. The blue line represents the ideal k_{ILIS} line, while the red lines show the behavior of a typical product.

An external RC filter between IS pin and the µC ADC input pin is recommended to reduce signal ripple and oscillations (a minimum time constant of 1 µs for the RC filter is recommended).

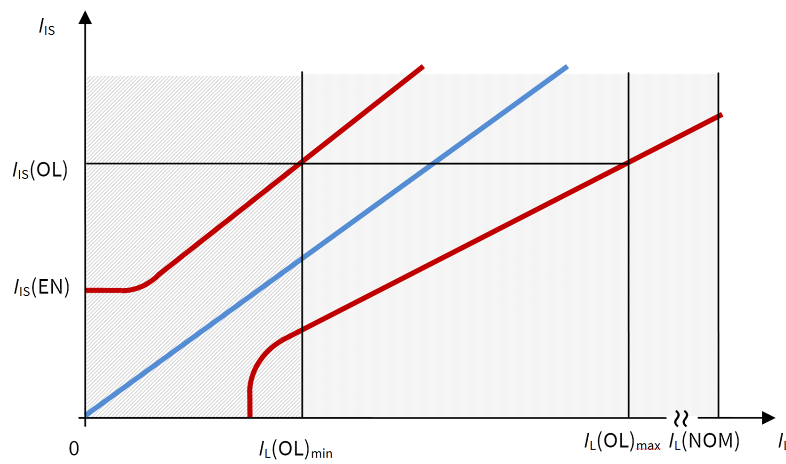

Figure 4 Current sense ratio in open load at ON condition

A protection event like overtemperature or overload can trigger a protection mechanism. If DEN is set to "high" and a protection event occurs, the value of the internal latch changes from 0 to 1 and, the IS pin provides a current equal to $I_{IS(FAULT)}$, and the affected device is switched OFF.

The switch can be unlatched using the IN pin or using the DEN pin.

Figure 5 shows the relation between $I_{IS} = I_L/k_{ILIS}$, $I_{IS(SAT)}$ and $I_{IS(FAULT)}$, considering their possible ranges.

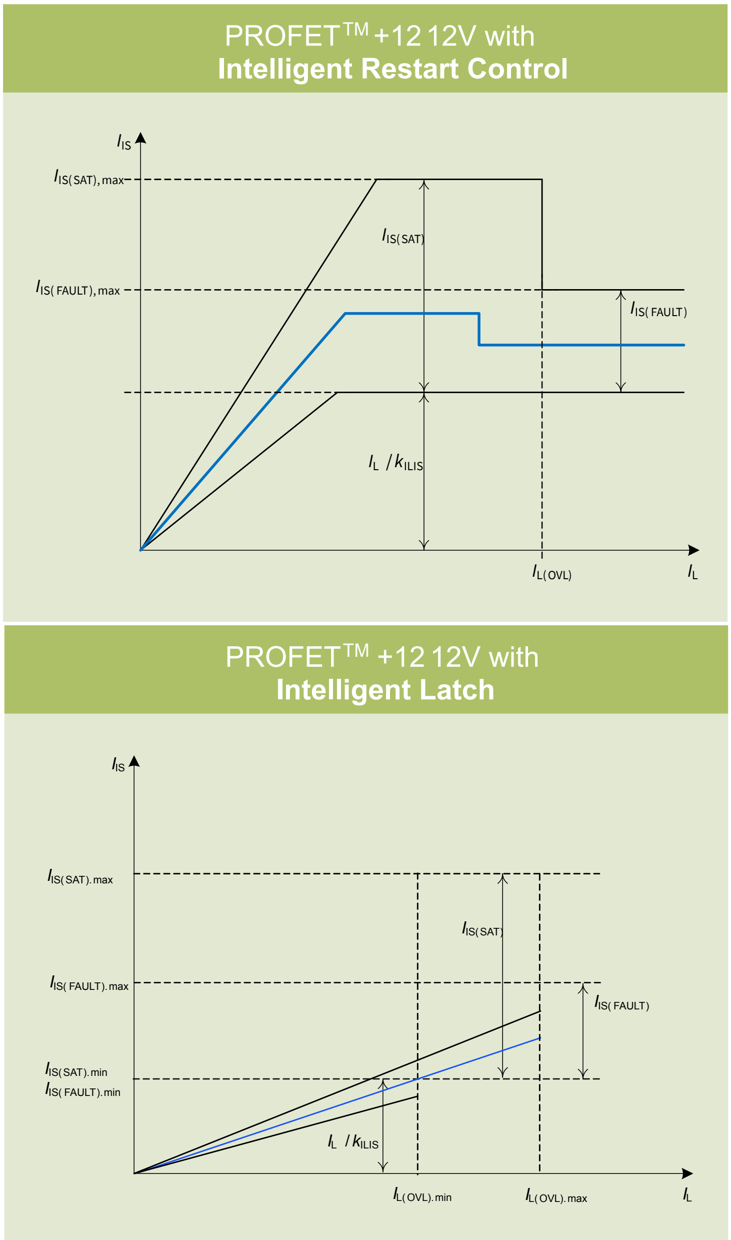

Figure 5 **SENSE behavior - overview**

1.3.1 Accuracy at low current

To realize a more accurate current sense function, especially at low current load, the output voltage limitation is implemented, monitoring V_{DS}.

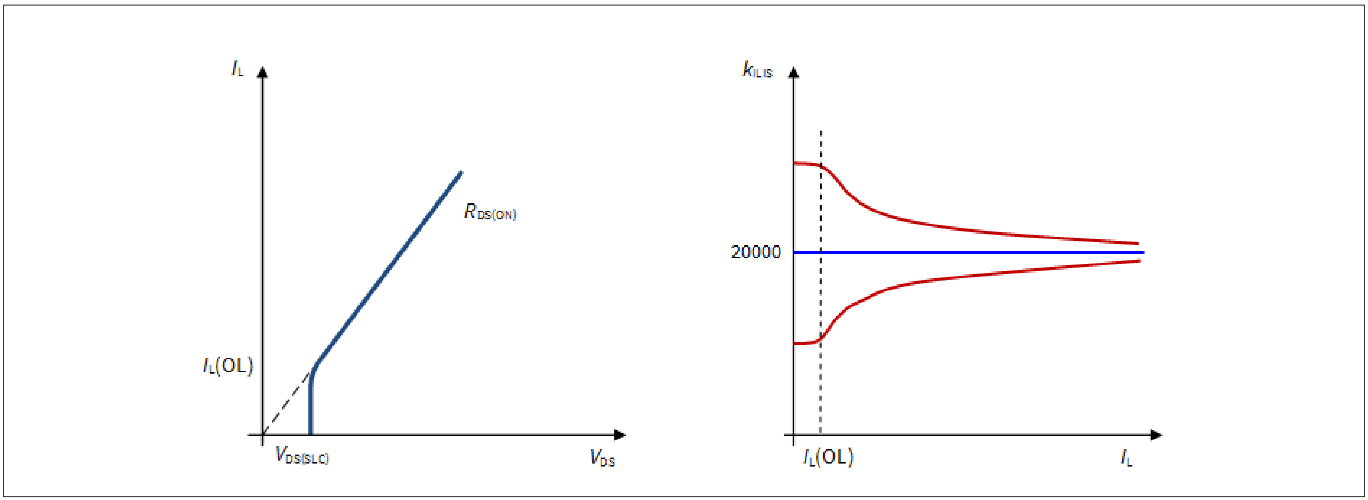

Figure 6 Power MOSFET characteristic and current sense ration with output voltage limitation

When the output current I_L decreases, while the channel is diagnosed (DEN pin set to “high”) bringing V_{DS}, equal or lower than $V_{DS(SLC)}$, the output DMOS gate is partially discharged, due to a circuitry that controls the gate. This increases the output resistance $R_{DS(ON)}$ so that $V_{DS} = V_{DS(SLC)}$, even for very small output currents.

The V_{DS} increase allows the Op-Amp, present in the current sensing circuitry, to work more efficiently, providing better k_{ILIS} accuracy for output current in the low range.

By controlling the voltage drop V_{DS}, the negative effect of the Op-Amp offset voltage V_{offset} is reduced and the sense accuracy is improved at small load currents as shown in ***Figure 6***.

1.4 Diagnosis in OFF state

If the diagnosis is enabled (DEN = 'high'), the diagnosis feature can be provided even if the power output stage is in OFF state. This mechanism is possible only measuring the drain-source voltage and compare it with a threshold voltage: condition of missing load, or short circuit to battery can be detected.

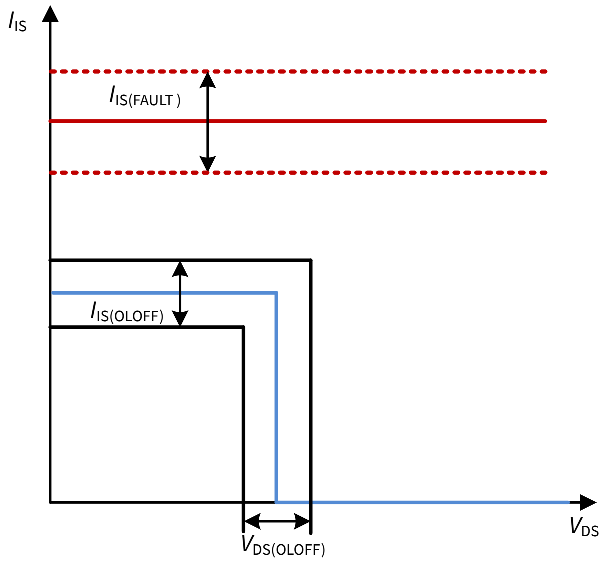

Figure 7 **I_{IS} in OFF state**

Also in OFF state a current $I_{IS(FAULT)}$ can be provided, if a fault condition was detected in the previous ON state, and if the internal latch is “1”. A fault current $I_{IS(FAULT)}$ will appear by IS pin, regardless of drain-source or output voltage, as long as DEN = 'high'.

If $V_{DS} \le V_{DS(OLOFF)}$, an open load condition will be detected, and only after a waiting time of $t_{IS(OLOFF)}$, a sense current $I_{IS(OLOFF)}$ will be provided. The $t_{IS(OLOFF)}$ is defined as the time between the falling edge of the input pin IN and the sensing at pin IS for open load in OFF diagnosis. This situation will occur only if the internal latch is “0”, otherwise the *IS* pin will provide a fault current $I_{IS(FAULT)}$.

In ***Figure 7*** the relationship between $I_{IS(OLOFF)}$ and $I_{IS(FAULT)}$ as functions of V_{DS} are shown. It is important to notice that the two currents do not overlap in order to differentiate between open load in OFF and fault condition.

With this, the complete diagnosis state of the device can be detected in OFF state which allows the µC software to be non-time critical reading and diagnosing the sense pin:

- I_{IS} = “low” nominal condition
- $I_{IS\ (OLOFF)}$ open load or short circuit to V_S or inverse current (if no $I_{IS(FAULT)}$ are present)
- $I_{IS(FAULT)}$ short circuit to GND or overtemperature from previous ON state

2 Error calculation

In this chapter the mathematical procedure for the inaccuracy or error calculation is explained.

For the PROFET™+2 12V family the relation between the load current I_L and the sense current I_{IS} is described through the relation:

$$I_{IS} = \frac{1}{k_{ILIS}} \cdot I_L$$

Equation 11

It is possible to compare this relation with the formula for a straight line:

$$y = m \cdot x + b$$

Equation 12

In which *x* is the independent variable, *y* is the dependent variable, *m* is the slope and *b* is the intercept with the *y* axis, or offset.

Comparing ***Equation 11*** and ***Equation 12***, it is possible to notice that I_L acts as independent variable, I_{IS} as dependent variable, k_{ILIS} is the slope, and there is no offset, because, assuming the ideal relation, the line will cross the zero-value.

The relationship between the sense current I_{IS} and the load current I_L should be linear with a fixed angular coefficient, as shown in ***Figure 8*** (a). In reality, inaccuracy can occur, in particular a slope (steepness) error and an offset, or combinations of both errors can show up. The slope error (in ***Figure 8*** (b)) is dependent on part-to-part production variation, and its effects are more pronounced at higher load currents.

The sense offset error (in ***Figure 8*** (c)) is caused by an internal amplifier offset voltage. It is strongly dependent on production variation and the operating temperature of the device. The effects of the offset are more pronounced at lower load currents.

Positive offset errors will results in a current at the IS pin, without a load current flowing. Negative offset errors will result in no current at the IS pin (theoretical negative sense current), even though load current is flowing. The sense functionality below a certain load current threshold will be disable. Load currents at this threshold or below will result in no sense current at the IS pin.

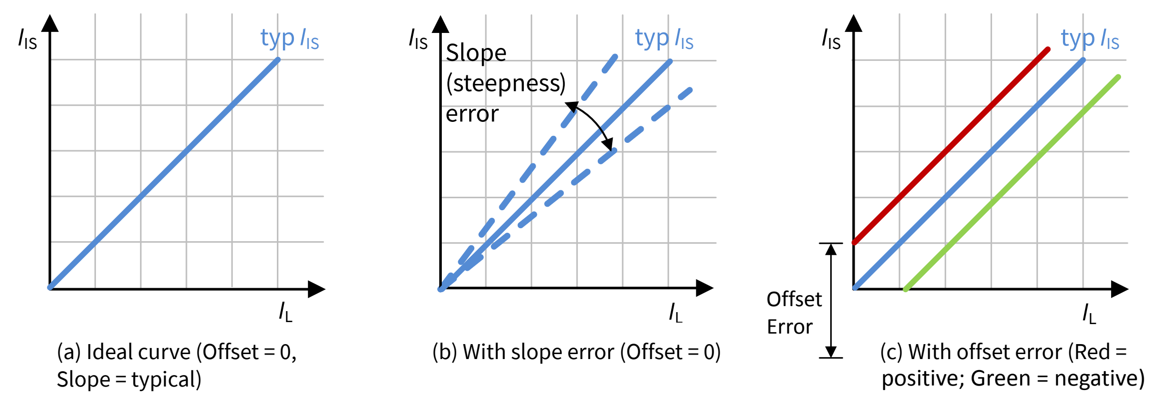

Figure 8 **Relationship between I_{IS} and I_L in conventional devices**

At this point the error measurements can be introduced, in order to value in which limits the *x* value may vary, assuming a certain *y* value is read. This procedure is applied only at the case shown in ***Figure 8*** (b), only slope error present, because it is done in the hypothesis that any offset error is present.

The typical straight line is described by the relation:

$$y = m_{TYP} \cdot x$$

Equation 13

If slope errors are considered, two other lines will be present, defined by the equations:

$$y = m_{MAX} \cdot x$$

Equation 14

$$y = m_{MIN} \cdot x$$

Equation 15

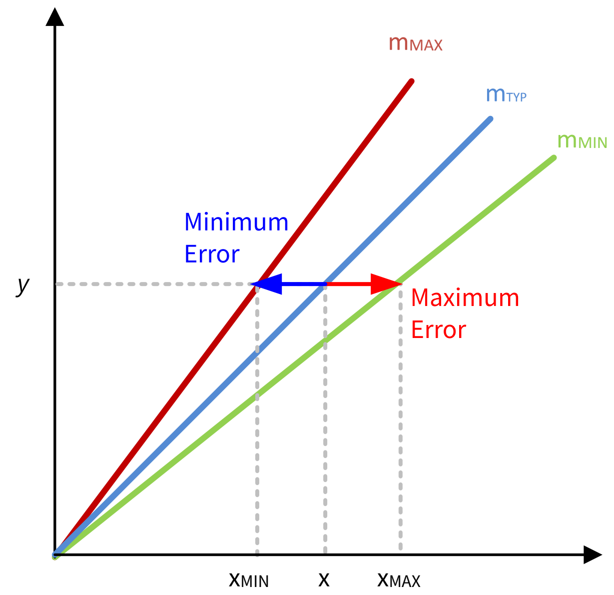

Figure 9 Graphic representation of minimum and maximum error

Assuming that a *y*-value is read, all *x*-values between x_{MIN} and x_{MAX} could be real as shown in ***Figure 9***. The difference between *x* and x_{MIN} and *x* and x_{MAX} are defining the minimum and maximum absolute errors:

$$MinAbsErr = x_{MIN} - x = \frac{y}{m_{MAX}} - x = \left(\frac{m_{TYP}}{m_{MAX}} - 1\right) \cdot x$$

Equation 16

$$MaxAbsErr = x_{MAX} - x = \frac{y}{m_{MIN}} - x = \left(\frac{m_{TYP}}{m_{MIN}} - 1\right) \cdot x$$

Equation 17

The minimum absolute error and the maximum absolute error represent the possible *x*-spreading, introduced by slope inaccuracy.

Normalizing for the *x* the minimum absolute error and the maximum absolute error, the minimum relative error and the maximum relative error can be obtained:

$$MinRelErr = \frac{x_{MIN} - x}{x} = \frac{y}{m_{MAX} \cdot x} - 1 = \frac{m_{TYP}}{m_{MAX}} - 1$$

Equation 18

$$MaxRelErr = \frac{x_{MAX} - x}{x} = \frac{y}{m_{MIN} \cdot x} - 1 = \frac{m_{TYP}}{m_{MIN}} - 1$$

Equation 19

The minimum relative error and the maximum relative error represent also the possible *x*-spreading, introduced by slope inaccuracy, but it is weighted for the *x* itself.

2.1 "Default" performance

In the PROFET™+2 12V family datasheet the typical k_{ILIS} parameters is specified for a load current range. The maximum and minimum values are also defined fixing the inaccuracy range. These inaccuracies are decreasing with increasing the load current, therefore for low current the inaccuracy range is broader then the high current range.

In ***Figure 4***, the behavior of I_{IS} curve is shown and it has been already described. In order to simplify this argument the following assumptions will be taken in account:

- At low current (< $I_{L(OL)}$) the relation $I_{IS} = I_L / k_{ILIS}$ is still valid;
- The slope of I_{IS} curve can vary from a limiting upper line to a limiting lower line according to k_{ILIS} range as defined datasheet.

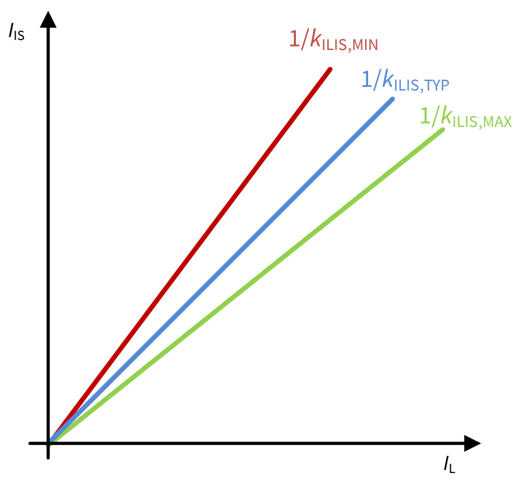

Figure 10 Simplified representation for the I_{IS} as function of I_L

These assumptions are applied and shown in ***Figure 10***.

The "Electrical Characteristics: Diagnosis – x mΩ" Table of the datasheet section "Diagnosis Power Output Stage – x mΩ" contains the "default" diagnosis performances for the PROFET™+2 12V family. Focusing on the BTS7004-1EPP, k_{ILIS} is specified for load currents from 200 mA up to 15 A.

From the parameters in the datasheet it is possible to derive:

- The typical slop m_{TYP} as:

$$m_{TYP} = {}^{1}\!/_{k_{ILIS,\,TYP}}$$

Equation 20

- The maximum slope m_{MAX} as:

$$m_{MAX} = {}^{1}\!/_{k_{ILIS,\,MIN}}$$

Equation 21

- The minimum slope m_{MIN} as:

$$m_{MIN} = {}^{1}\!/_{k_{ILIS,\,MAX}}$$

Equation 22

These slope parameters are describing the limiting lower line and the limiting upper line of the measurable load current range.

Applying the PROFET™+2 12V family parameters from ***Equation 16*** to ***Equation 19*** results in the following equations:

$$MinAbsErr = \left(\frac{m_{TYP}}{m_{MAX}} - 1\right) \cdot I_L$$

Equation 23

$$MaxAbsErr = \left(\frac{m_{TYP}}{m_{MIN}} - 1\right) \cdot I_L$$

Equation 24

$$MaxRelErr = \frac{m_{TYP}}{m_{MIN}} - 1$$

Equation 25

$$MinRelErr = \frac{m_{TYP}}{m_{MAX}} - 1$$

Equation 26

It is worth noting that the maximum relative error and the minimum relative error, with these assumptions, are depending only on the ratio between the slopes.

In ***Table 1*** the results for the “default” current sense performance are shown for the BTS7004-1EPP, for load current I_L from 200 mA to 15 A.

In term of accuracy it can be seen that the “default” accuracy reaches at nominal current (I_L = 15 A) 8%, that is the minimum value. Furthermore, the maximum relative error and the minimum relative error are decreasing when increasing the load current, because relative k_{ILIS} accuracy improves at “high” current.

Table 1

I_L [A]	Maximum absolute error [A]	Maximum relative error [%]	Minimum absolute error [A]	Minimum relative error [%]
0.05	0.03	65	-0.03	-65
0.2	0.13	65	-0.13	-65
0.45	0.25	55	-0.25	-55
2	0.80	40	-0.80	-40
5.5	1.32	24	-1.32	-24
10	0.80	8	-0.80	-8
15	1.20	8	-1.20	-8

It could be interesting to analyze the accuracy across Low Current and Nominal Current range, in particular from I_L = 450 mA to I_L = 6.5 A.

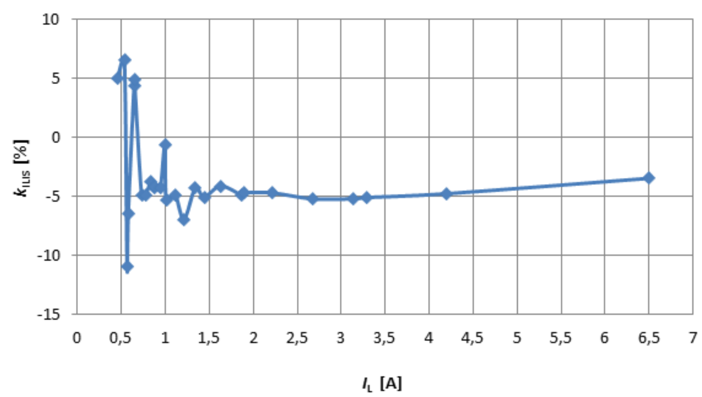

Figure 11 k_{ILIS} **measurements results across low and nominal current range at different** T_J **and** V_{bb}

In *Figure 11* measurement results are shown. These measurements have been conducted at T_J = 25°C and with a supply voltage V_S = 13.5 V. The k_{ILIS} accuracy is still confined in range of accuracy defined in the datasheet.
It could be also interesting to note how the k_{ILIS} behaves if a current range, above the nominal, is investigated.

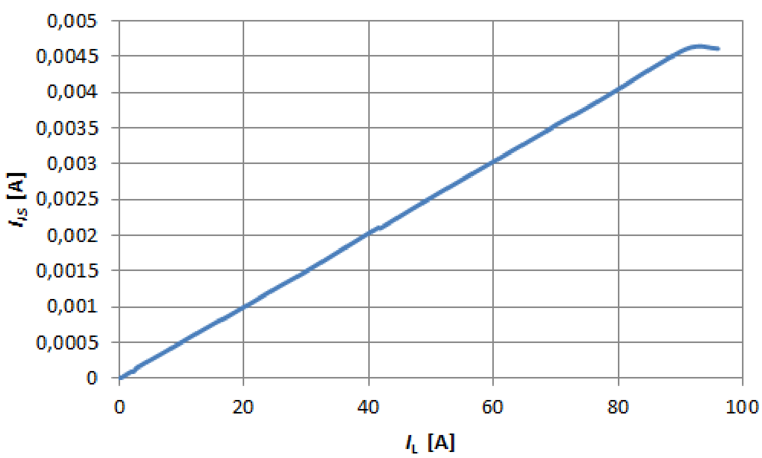

Figure 12 k_{ILIS} **measurements results at high current range**

In *Figure 12* measurement results are shown. These measurements have been conducted at T_J = 25°C, with a supply voltage V_S = 13.5 V. This behavior proves the $I_{IS(SAT)}$: behavior shows the accuracy of the sense current up to the saturation level.

2.2 1-Point calibration performance

One option to improve the current sense performance is the 1-Point calibration , obtaining tighter limits of accuracy if compared to the “default” overall sense performance. The 1-Point calibration offers the lowest measurement effort of all possible calibration options.

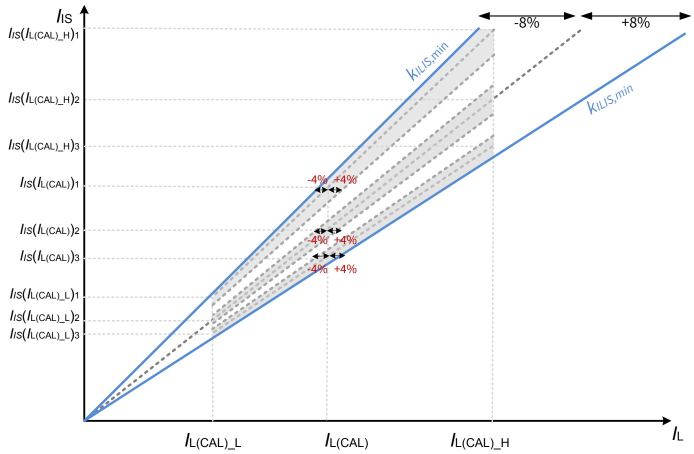

Figure 13 **k_{ILIS} parameter for the BTS7004-1EPP**

Figure 13 shows the k_{ILIS} parameter for the BTS7004-1EPP, when the 1-Point calibration is used on three different samples in the range delimited by $I_{L(CAL)\_L}$ and $I_{L(CAL)\_H}$, the sense accuracy can be tighten from 8% to 4% for definite load currents.

The idea behind the 1-Point calibration in mathematical terms is:

- Fix x_1
- Identify the point (x_1, y_1)
- Calculate m as:

$$m = \frac{y_1}{x_1}$$

Equation 27

This procedure can be extrapolate from *Equation 11*, in the hypothesis that the straight line crosses that zero-value, therefore $b = 0$. This situation is shown in *Figure 14*.

In the real case, 1-Point calibration procedure is based of the following steps:

- Fix I_L
- Measure $I_{IS}(I_L)$
- Calculate m as:

$$m_{CAL} = \frac{I_{IS}(I_L)}{I_L}$$

Equation 28

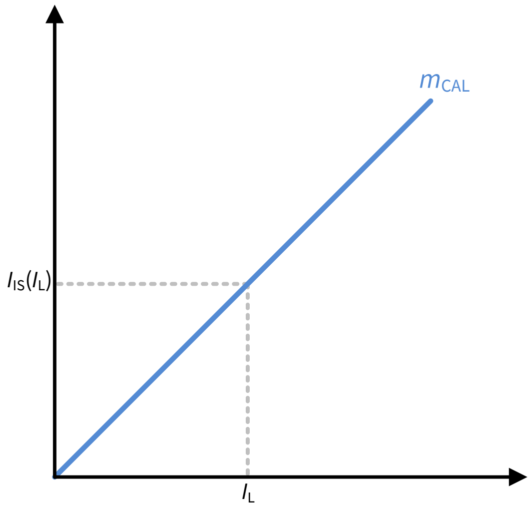

Figure 14 **Schematic representation of 1-Point calibration procedure for a genic I_L-I_{IS} line**

To measure current sense at very low current gate back regulation is present.

For this reason the problem is split in two parts: low current and nominal current.

Once m_{CAL} is calculated, variation effects should be taken into account. In the datasheet the parameters $\Delta k_{ILIS(OL)}$ (Sense Current Derating with Low Current Calibration) and $\Delta k_{ILIS(NOM)}$ (Sense Current Derating with Nominal Current Calibration) are specified. Measuring the sense current I_{IS} after calibration, it is possible to calculate the load current I_L with the accuracy defined by the Sense Current Derating parameters.

In order to quantify the 1-Point calibration accuracy, the calculation of the maximum absolute and minimum absolute error is carried out. Equations from ***Equation 23*** to ***Equation 26*** can be used for this purpose if m_{TYP} is replaced with m_{CAL}; m_{MIN} and m_{MAX} can be calculated as following:

$$m_{MIN} = \frac{m_{CAL}}{1 + max(\Delta k_{ILIS})}$$

Equation 29

$$m_{MAX} = \frac{m_{CAL}}{1 - min(\Delta k_{ILIS})}$$

Equation 30

Where Δk_{ILIS} is intended as $\Delta k_{ILIS(OL)}$ for low current range and $\Delta k_{ILIS(NOM)}$ for nominal current range.

For the BTS7004-1EPP, the considered low current range starts from 50 mA to 450 mA, and the nominal current range goes from 5.5 A to 15 A.

Figure 15 shows a graphic representation of maximum absolute error and minimum absolute error for low and nominal currents, for the BTS7004-1EPP.

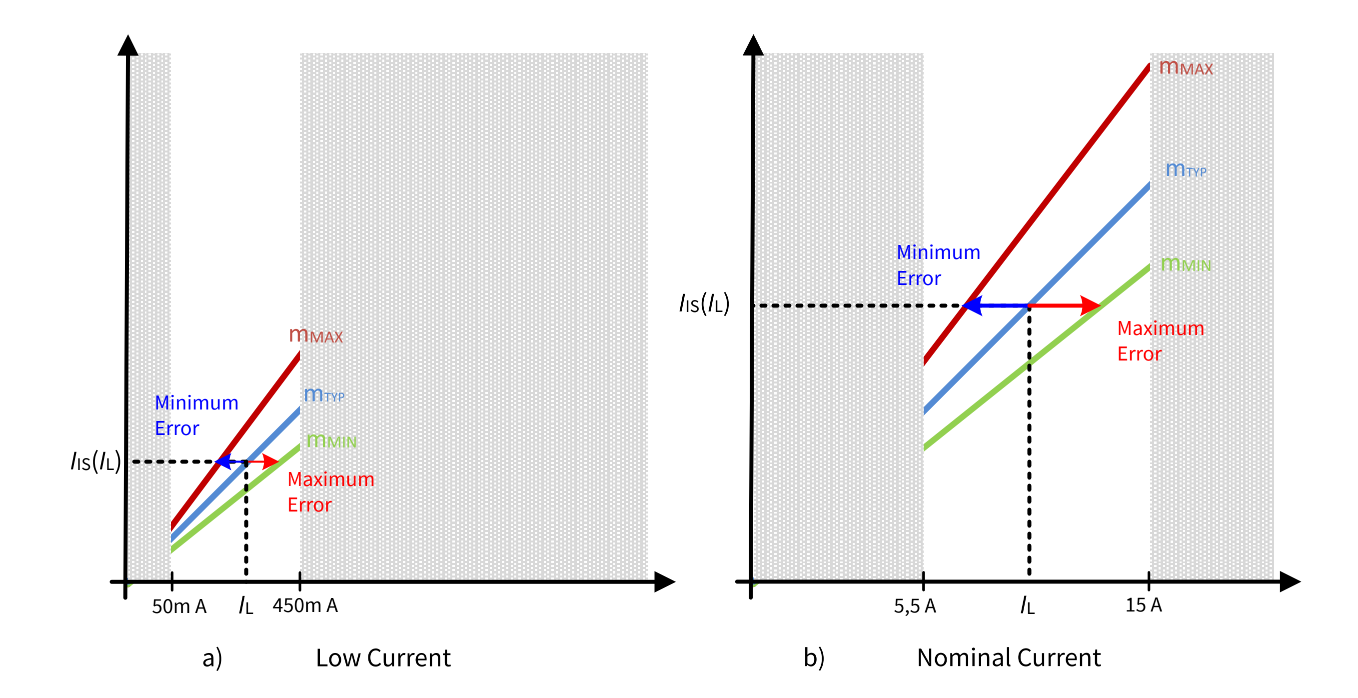

Figure 15 **Graphic representation of minimum and maximum error for low and nominal current ranges**

Table 2 shows maximum and minimum absolute errors and maximum and minimum relative errors for low current ranges for the BTS7004-1EPP with a calibration current I_L = 0.2 A.

Table 3 shows maximum and minimum absolute errors and maximum and minimum relative errors for nominal current ranges for the BTS7004-1EPP with a calibration current I_L = 10 A.

It is possible to compare the results from ***Table 2*** and ***Table 3*** with the results showed in ***Table 1***. For both Low Current Range and for Nominal Current Range the calibration 1-Point calibration improves the accuracy compared to the “default” performance.

The same comments done for the “default” performances are valid for the 1-Point calibration performance:

- The minimum value is reached at nominal current (I_L = 15 A) 4%
- The maximum relative error and the minimum relative error are decreasing increasing the load current

Table 2

I_L [A]	Maximum absolute error [A]	Maximum relative error [%]	Minimum absolute error [A]	Minimum relative error [%]
0.05	-1.50E-02	-30	1.50E-02	30
0.2	-6.00E-02	-30	6.00E-02	30
0.45	-1.35E-01	-30	1.35E-01	30

Table 3

I_L [A]	Maximum absolute error [A]	Maximum relative error [%]	Minimum absolute error [A]	Minimum relative error [%]
5.5	-0.22	-4	0.22	4
10	-0.4	-4	0.4	4
15	-0.6	-4	0.6	4

From another point of view, the previous results represent the accuracy which, measuring the sense current I_{IS}, it is possible to know the load current I_L. After the 1-Point calibration, measuring a sense current I_{IS}, it is possible to obtain a load current value with a derating of ±4%.

3 Practical procedure

In this paragraph the calibration techniques previously discussed are presented in terms of practical example.

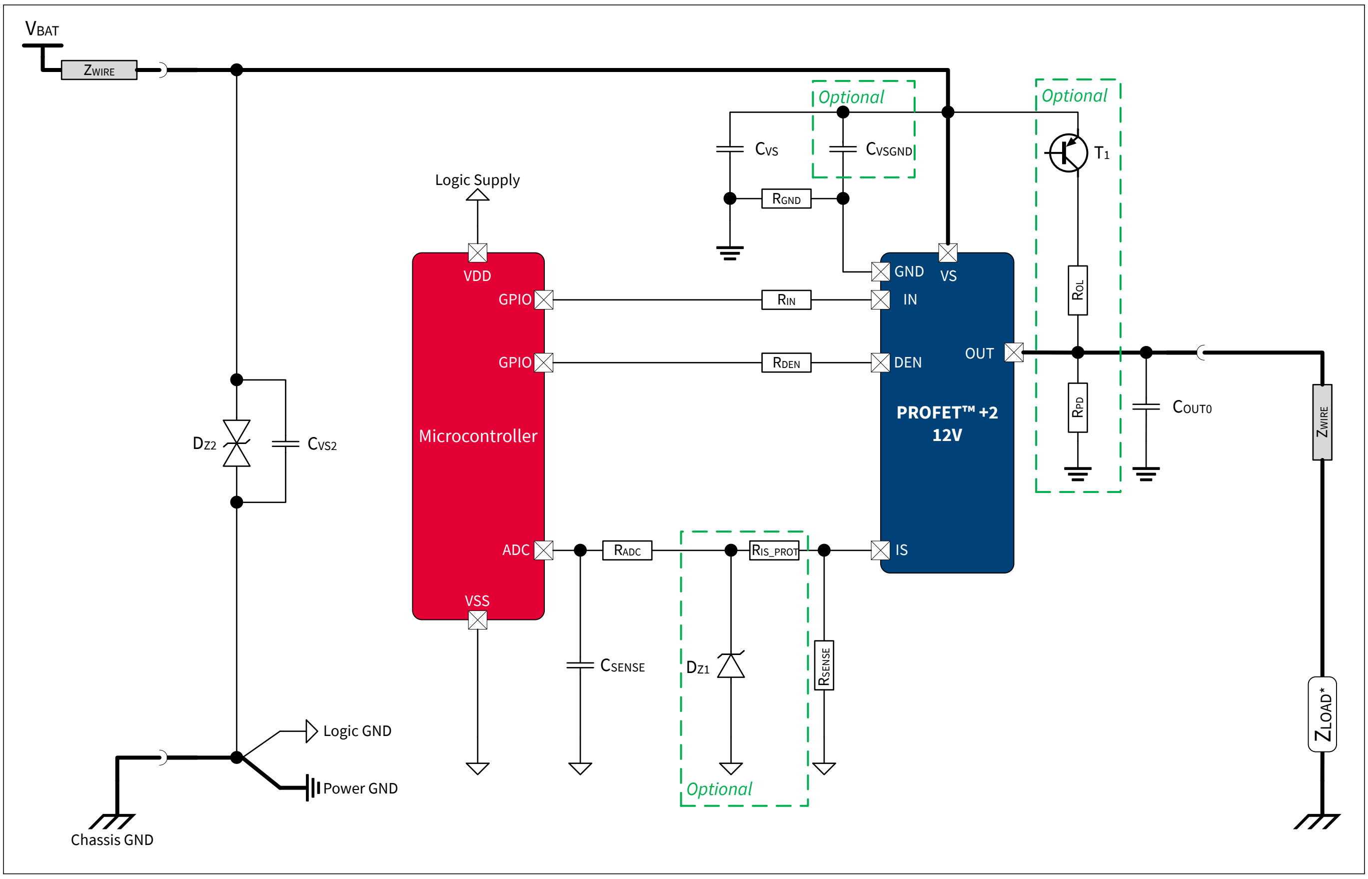

Figure 16 **Single channel application diagram**

In a general application, a microcontroller is used in order to monitor the sense current I_{IS}. The µC is able to read voltage through the ADC ports, therefore it measures the voltage V_{IS} across the sense resistor R_{SENSE}, as shown in ***Figure 16*** .

Note: This is a very simplified example of an application circuit focusing on sense accuracy. The function must be verified in the real application. Further application hints can be found in the datasheet in the paragraph "Application Information".

The voltage V_{IS} is seen by the ADC input in the microcontroller as:

$$V_{IS} = R_{SENSE} \cdot I_{IS}$$

Equation 31

$$I_L = k_{ILIS,\,TYP} \cdot I_{IS} = k_{ILIS,\,TYP} \cdot \frac{V_{IS}}{R_{SENSE}}$$

Equation 32

Where $k_{ILIS,TYP}$ is the typical value for the k_{ILIS} specified in the data sheet for a fixed load current I_L.
In case of 1-Point calibration, the load current I_L can be calculate as:

$$I_L = k_{ILIS,CAL} \cdot I_{IS}\left(I_L\right) = k_{ILIS,CAL} \cdot \frac{V_{IS}(I_L)}{R_{SENSE}}$$

Equation 33

Where $k_{ILIS,CAL}$ is calculated as the ratio between the fixed load current I_L and the measured I_{IS}.

3.1 "Default" behavior

This procedure is the least expensive in terms of time and manufacturing effort, but it is the least accurate. This option does not require that any value should be stored, instead it needs the knowledge of values as k_{ILIS}, specified in the data sheet.

The term "device", used in the flowchart in ***Figure 17***, refers to the high-side switch tested.

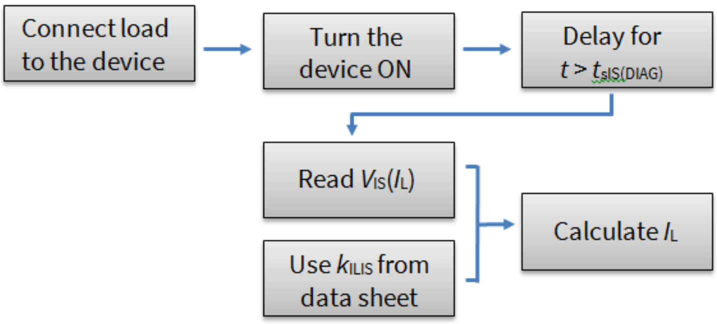

Figure 17 Manufacturing procedure for the default behavior

After a load is connected, the device can be switched ON, but a time delay of $t_{sIS(DIAG)}$ is needed before the voltage V_{IS} is read by the microcontroller. This time delay is defined as:

$$t_{sIS(DIAG)} \leq 3 \cdot \left(t_{ON\_MAX} + t_{sIS(ON)\_MAX}\right)$$

Equation 34

Where t_{ON_MAX} is the maximum switch ON time, and $t_{sIS(ON)\_MAX}$ is the maximum sense settling time with Nominal Load Current Stable.

Using the k_{ILIS} value from the data sheet, after V_{IS} reading, the load current I_L can be calculate using ***Equation 32***.

Comparing then the obtained I_L value with threshold limits, load condition can be determine (e.g. Nominal, Overload, Short circuit to V_s, etc.).

3.2 1-Point calibration

1-Point calibration practical test is usually carried out at temperature of 25°C. It is based on the measurement of V_{IS} (I_L), that is the voltage across the sense resistor R_{SENSE}, when a load current I_L is previously chosen. ***Figure 18*** shows the procedure for 1-Point calibration.

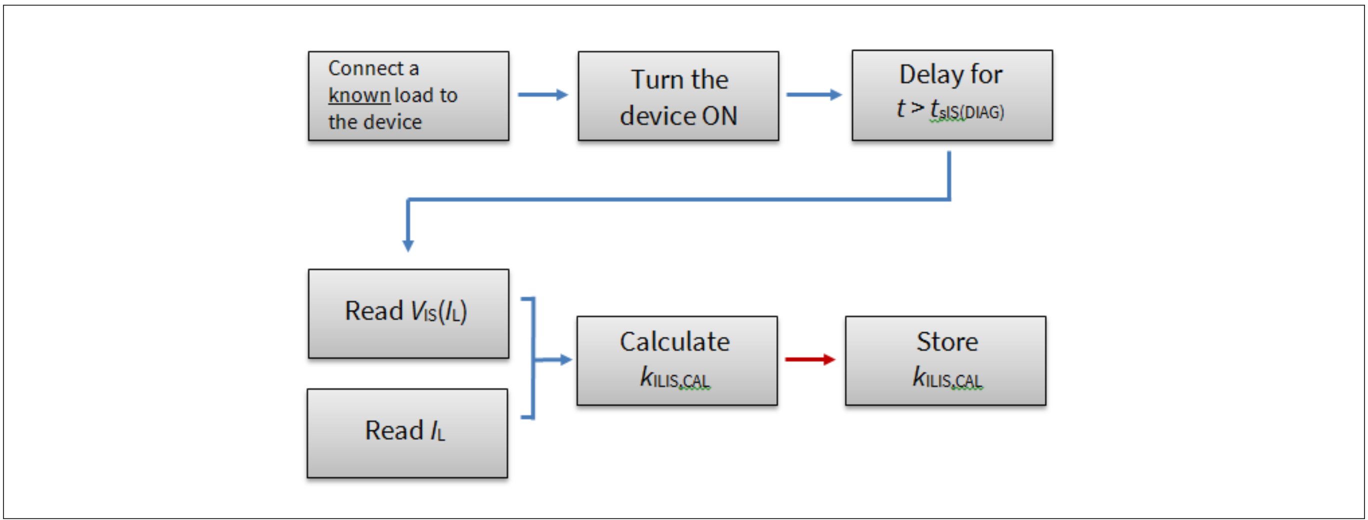

Figure 18 Manufacturing procedure for 1-Point calibration

After a known load is connected, the device can be switched ON, but a time delay of $t_{sIS(DIAG)}$ is needed to be waited, before the voltage V_{IS} is read by the microcontroller. The parameter $k_{ILIS,CAL}$ can be calculated and store in NVM (non-volatile memory).

The next measurements are going to use this $k_{ILIS,CAL}$ value in order to calculate I_L: the flowchart in ***Figure 17*** can be used, using $k_{ILIS,CAL}$ instead of $k_{ILIS,TYP}$.

The obtained I_L value can be compared with the nominal current or with threshold limits, in order to determine load conditions.

Note: Note: The accuracy of the measurement depends on several components of the system, e.g.: sense resistor, AD-converter of microcontroller, known load.

4 Conclusion

The PROFET™+2 12V family provides protection functions and diagnosis.

For diagnosis purpose, it provides a sense current signal (I_{IS}) at pin IS in order to detect:

- Proportional load current sense
- Open load in ON and OFF state
- Short circuit to ground and battery

A current proportional to the load current (ratio $k_{ILIS} = I_L/I_{IS}$) is provided at pin I_S with a “default” accuracy. The sense current accuracy tolerance/spread widens at lower load currents.

If the default accuracy does not fulfill the application requirements, 1-Point calibration can performed. 1-Point calibration is the easiest calibration technique in terms of manufacturing effort.

With the PROFET™+2 12V, Infineon Technologies offers protected high side switch with very good current measurement accuracy.

Revision history

Document version	Date of release	Description of changes
1.2	2019-09-05	Changed *"New High Current PROFET™ family"* and *"High Current PROFET™ family"* with *"PROFET™+2 12V"*. Typos corrected. ***Figure 2***, ***Figure 5***, ***Figure 16*** updated.
1.1	2018-02-14	Editorial changes, typos corrected.
1.0	2018-01-22	Initial release.

Trademarks

All referenced product or service names and trademarks are the property of their respective owners.

Edition 2019-09-05

Published by

Infineon Technologies AG

81726 Munich, Germany

Do you have a question about any aspect of this document?

Email: erratum@infineon.com

Document reference
IFX-dfg1507631667444